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AN ALTERNATIVE TO DEGREE DAYS FOR CROP GROWTH AND DEVELOPMENT STUDIES

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1. INTRODUCTION

The conventional wisdom with regard to Day Degree units is that the individual components that go to make up the units are of equal significance; time duration above the base temperature and the temperature excess carry equal weight; 10 days, each with a mean temperature excess of 1 deg C are, in total, equivalent to 1 day with a mean temperature excess of 10 deg C.

The success of Day Degree units in summarising or integrating environmental and climate requirements for crop growth and development is only as great as one might expect from a first order approximation.

2. TEMPERATURE AND RATE OF METABOLIC REACTIONS

In looking for an improvement on the Day Degree approach, in particular over those phases of production where photosynthesis is not relevant but where temperature might be expected to exercise a prime direct control, for example at germination and on the breaking of dormancy of roots and bulbs in store, it would seem not unreasonable to note that in the limit we deal with chemical reactions. Such reactions show generally an increase with temperature.

A reaction rate necessarily implies the (metabolic) change achieved in a unit of time. A reaction rate, multiplied by the time interval over which the rate applies, indicates the total (metabolic) change during the time interval. If this idea is used, then higher temperatures automatically carry a greater weight than lower temperatures, in contrast to the Day Degree approach, where all temperatures above the base carry equal weight.

The temperature coefficient of chemical reactions is commonly defined in terms of the ratio of the reaction rates at 2 temperatures differing by 10°C. Such temperature coefficients generally have a value between 2 and 3, though lower, as well as higher values are also found.

If K_{10} = reaction rate at 10°C

K_0 = reaction rate at the base temperature of 0°C

and

$$K_{10}/K_0 = 2.5 \text{ (say)}$$

then at any intermediate temperature to between 0° and 10°C a simple form is

$$K_t = K_0 [1 + 1.5\ t/10]$$

By extension, for a value of t between 10° and 20°C

$$K_t = K_{10} [1 + 1.5\ (t-10)/10]$$

$$K_t = 2.5\ K_0 [1 + 1.5\ (t-10)/10]$$

The derivation for other temperatures (t) and for base temperatures other than 0°C is straightforward.

3. APPLICATION

The following table, taken from the literature, shows the percentage sprouting of onions stored for different periods at different temperatures.

Table Percentage sprouting of onions

Duration in store	2 months	4 months	6 months
Storage temperature			
0°C	0 %	0 %	6%
1.7°C	0	12	89
4.4°C	2	66	99
8.9°C	28	89	100

With (internal) moisture seen as non limiting and with temperature as the prime control, it is of interest to see whether the data of the table above can be brought together in one simple relationship.

If Day Degrees above a base of 0°C are calculated for the combinations of the table above, we obtain the information set out in Table 1.

TABLE I

Time in Store	Temperature Excess	Accumulated Day Degrees	Sprouting
60 days	0°C	0	0%
120	0	0	0
180	0	0	6
60	1.7°C	102	0
120	1.7	204	12
180	1.7	306	89
60	4.4°C	264	2
120	4.4	528	66
180	4.4	792	99
60	8.9°C	534	28
120	8.9	1068	89
180	8.9	1602	100

The data of Table I are graphed in Figure 1. The location of the expected sigmoid curve is not closely defined and a best fit is drawn by eye.

If, as an alternative, we define an accumulated metabolic change (M) during a time interval of D days, on each of which the mean temperature excess above a base of 0°C is t°C (where $0° \leq t \leq 10°C$) we may write.

$$M = D\,k_t$$

$$M = D\,k_o\,[1 + 1.5t/10]$$

The values of M derived from the basic data are set out in Table 2.

TABLE 2

Time in store	Reaction rate	M	M/k_o	Sprouting
60 days	k_o	60 k_o	60	0%
120	k_o	120 k_o	120	0
180	k_o	180 k_o	180	6
60	$k_o [1 + 1.5 \times 1.7/10]$	75 k_o	75	0
120	"	151 k_o	151	12
180	"	226 k_o	226	89
60	$k_o [1 + 1.5 \times 4.4/10]$	100 k_o	100	2
120	"	199 k_o	199	66
180	"	299 k_o	299	99
60	$k_o [1 + 1.5 \times 8.9/10]$	140 k_o	140	28
120	"	281 k_o	281	89
180	"	421 k_o	421	100

The data of table are graphed in Figure 2. The best fitting curve is drawn by eye.

4. A NUMERICAL COMPARISON

If correlations are calculated (for the 12 observed values) between observed and predicted values of percentage sprouting - predicted values being given by the sigmoid curves of figures 1 and 2, then the correlations obtained are

For accumulated degree day data $r = .82$
For accumulated metabolic change data $r = .95$

5. DISCUSSION

Given the typical spread of biological field data, no single environmental parameter can be expected to lead to 1 to 1 relationships.

On very limited evidence, the accumulated metabolic change units (M/k_o) defined above would appear to offer some advantage over degree days.

The extension to other phases of crop growth needs exploration, but the approach could be valid for example in the light saturated, photosynthesis situation.

The extension to other biological situations, such as pest emergence, is possibly worth investigation.

Meteorological Office
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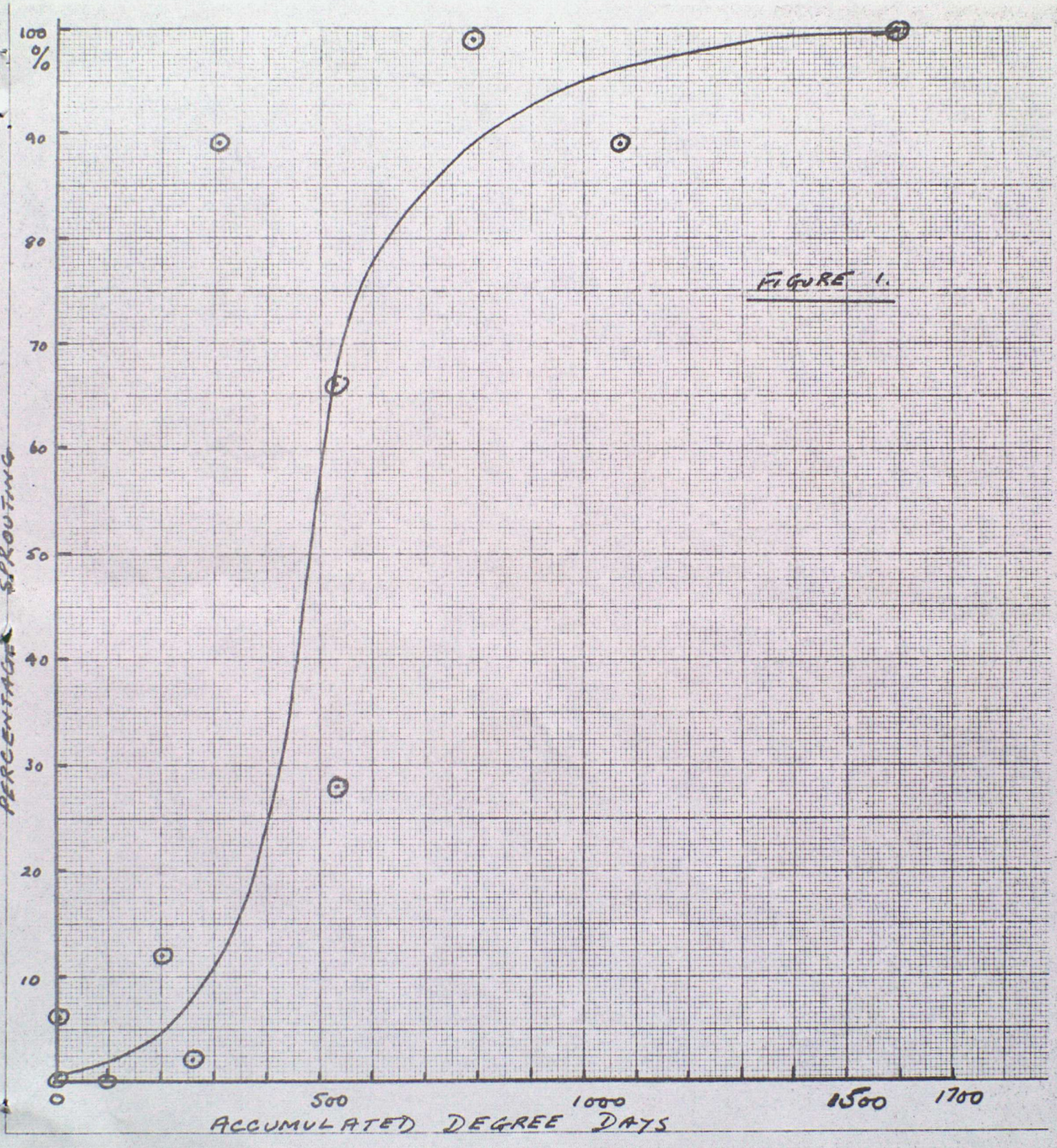
100 %
90
80
70
60
50
40
30
20
10
PERCENTAGE SPROUTING
0
500
1000
1500
1700
ACCUMULATED DEGREE DAYS

FIGURE 1.

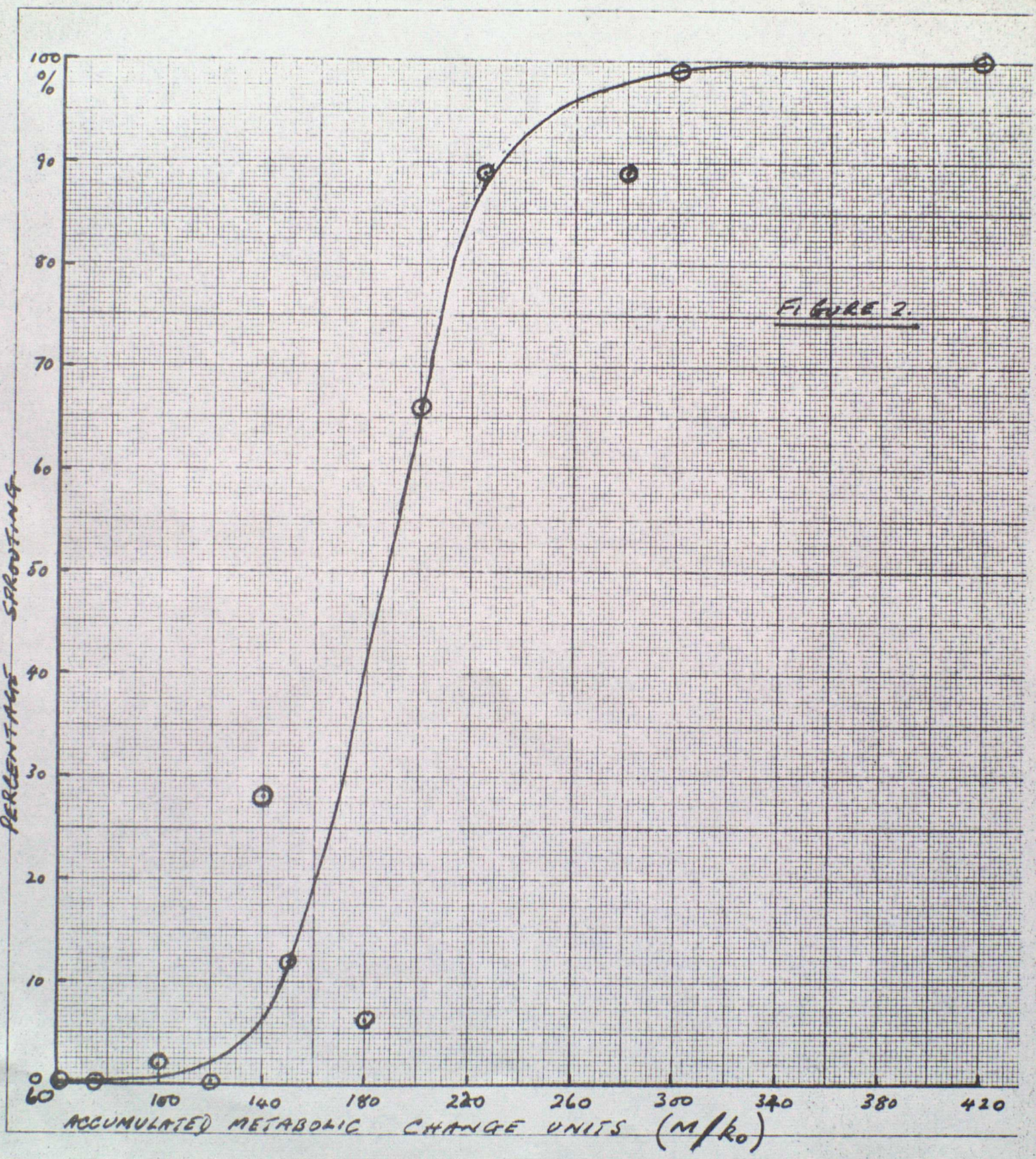
100
%
90
80
70
60
50
40
30
20
10
0
60
100
140
180
220
260
300
340
380
420
PERCENTAGE SPROUTING
ACCUMULATED METABOLIC CHANGE UNITS (M/k₀)

FIGURE 2.